The variation in pressures exerted by commercially available compression garments

Original Investigation

Abstract

Commercially available compression garments (CGs) demonstrate the enhanced recovery from exercise in some, but not all studies. It is possible that in some cases the degree of compression pressure (ComP) exerted is not sufficient to produce any physiological benefit. The aim of this investigation was to identify the levels of ComP exerted by commercially available CGs. This study was composed of two parts. In part A 50 healthy, physically active individuals (n=26 male, n=24 female) were fitted with CGs according to manufacturer's guidelines. ComP was measured in participants standing in the anatomical position with a pressure measurement device inserted between the skin and the garment. Data were compared to 'ideal' pressure values proposed in the literature. In part B ComP in three different brands of CG were compared in a population of 29 men who all wore a medium sized garment. A one way ANOVA indicated that there was a significant difference ($P<0.05$) between observed pressure and ideal pressure at the quadriceps for males and females and in the calf for the female population. There was no significant difference ($P>0.05$) between observed and ideal pressures in the calf of the male population. No significant differences in pressure ($P>0.05$) were observed between CG brands at the quadriceps or calf. In conclusion a large number of individuals may not be experiencing an adequate ComP from CG, and this is true for all 3 of the major brands of CGs tested in this investigation.

Keywords: Recovery, Stockings, Tights, Sports, Athletes

Introduction

The use of commercially available compression garments (CGs) is becoming increasingly popular within an athletic setting [1-3]. It is claimed that CGs can improve performance, reduce fatigue and enhance recovery [4]. However, the known studies show mixed results, with some supporting the use of CGs [5-8] and others observing no benefits [9]. Compression pressure (ComP) seems to be one of the major factors that potentially determines their efficacy.

Manufacturers recommend that lower limb CGs (tights) are fitted according to the height and mass of an individual [10], however, the variation in limb size and tissue structure within a given population is likely to affect the fit, particularly when standard sizing categories are used [11]. Thus wide inter-individual variation may exist in the ComP exerted by CGs [12]. Ashdown [13] also indicated that sizing systems used to create 'ready to wear' garments are flawed, due to the lack of size variation available to fit the wide range of body types within a population. A large number of studies do not specifically measure the ComP exerted by the CGs used within their study. These studies either fail to report the level of ComP altogether [8, 14-16], report the ComP indicated by the manufacturers of the product, or reference ComP reported in previous research that has used the same brand of garment [11, 17-20]. It has been suggested that the measurement of interface pressure between the skin and the garment is essential in evaluating the efficacy of a garment [21]. Consequently, the ComP should be measured for each individual because the degree of compression exerted by a garment is dependent on the individual size and shape of the body [20] and not necessarily on the height and mass.

To date, the ideal ComP required to be beneficial to performance and recovery has not been defined. CGs, particularly lower limb garments, are purported to be graduated, with the highest ComP exerted at the ankle and decreasing towards the thigh, thereby creating a pressure gradient [22]. Reported (but not specifically verified) levels of ComP exerted by CGs used in recent research range from 10-12 mmHg [19] to 18-22 mmHg [11]. Clinical grade CGs exerting pressures of 30-60 mmHg are frequently prescribed for a range of medical purposes [23]. It has been suggested that for compression to be effective in modulating haemodynamic factors, the ComP must be sufficient to cause a narrowing of the superficial blood vessels; and in order for this to occur the compression must be greater than intravenous pressure [24]. In a supine position, venous pressure in the lower limb is approximately 10-15 mmHg, however these pressures are much higher when standing (30-90 mmHg) [24]. This indicates that the level of compression required to be of benefit may be dependent upon body position. Compression pressures of 10-15 mmHg have been shown to be effective in reducing the diameter of superficial veins in a supine position, however much higher pressures are required to achieve the same results when standing [24]. In contrast, Watanuki and Murata [25] observed improved cardiac output and venous return with ComP of 20 mmHg at the thigh and 25 mmHg at the calf. The authors of this study estimated that the minimum ComP required to improve venous return is 17.3 mmHg at the calf, decreasing to 15.1 mmHg at the quadriceps. Hypothetically, if individuals are not receiving a physiologically effective ComP, the CGs may have no effect on recovery or performance.

Ali et el [26] investigated the effects of different grades of compression garments with high (32mmHg at the ankle and 23mmHg at the knee) low (15mmHg at the ankle and 12mmmHg at the knee) and no compression, on 40 minute running performance. Although no benefits of the compression garments were observed on performance or recovery, participants found the low grade compression garments more comfortable. Whilst there are no studies that indicate optimal levels of compression in the sporting field, clinical research had found positive results with ComP of 15-30 mmHg at the ankle dissipating at the thigh [26-28]. Research has also indicated that high ComP (approximately 30 mmHg at the calf) may impair blood flow and restrict venous return [29]. With this in mind the ComP observed in this study is compared to the ComP suggested by Watanuki and Murata [25].

Current evidence for the benefits of using CGs remains equivocal or weak at best. This may be because the popular commercially available garments do not exert sufficient enough pressure to be of benefit. Defining the exact ComP achieved with CGs would enable detailed investigations into the optimum ComP required to affect performance and recovery, and will improve our ability to interpret research findings [12]. Therefore the primary aim of this investigation was to identify the ComP exerted by commercially available lower limb CGs across a representative sample of physically active male and female population. The secondary aim was to identify whether there was consistency in the amount of ComP exerted between different brands of similar products.

Methodology

Participants

This study was composed of two parts.

Fifty participants, having different body sizes (male: n=26; female: n=24), were recruited to participate in part A of the study, in order to establish ComP exerted by commercially available garments. Twenty nine male participants were recruited to participate in Part B of the study, in order to investigate variability in ComP for different product brands. A medium sized garment from 3 different brands was selected (participant characteristics can be seen in table 1). All participants were healthy, physically active and exercised minimum 3 times per week. Procedures were approved by the University ethics committee, in accordance with the Declaration of Helsinki and all participants gave written, informed consent and completed a health screening questionnaire. Participants were asked to refrain from heavy exercise in the 48 h preceding the testing session and were excluded from the study if they had a chronic illness or if they were experiencing any musculoskeletal pain or discomfort.

Procedures

Anthropometric data were collected from all participants including height and weight; waist, hip and gluteal circumference; thigh, calf and ankle girth and skinfold measurements from 7 sites (bicep, tricep, subscapular, supraspinale, abdomen, front thigh and medial calf). All girth and skinfold measures were taken from the right leg, in accordance with ISAK guidelines. All measures were taken by a level 2 anthropometrist. The technical error of measurement (TEM) for each anthropometric variable is reported in Table 2.

Following anthropometric data collection, male and female participants in part A of the study were fitted with a pair of CGs from one brand (2XU, MA1551b men's compression tights or WA1552b women's compression tights, Melbourne, Australia). Garments were fitted based upon the height and weight of the participant, according to manufacturer guidelines. All participants were either a small, medium or large in traditional garment size (none of the participants required a tall sized garment).

Part B involved a comparison between 3 different brands of CGs in male participants only. Garment A (2XU, MA1551b men's compression tights) fitted participants in a height and weight range of 150-185cm and 65-90kg respectively, garment B (Skins, A400 men's compression tights, Campbelltown, Australia) fitted participants in a height and weight range of 170-190cm and 70-85kg respectively and garment C (Linebreak, men's velocity compression tights, Sydney, Australia) fitted participants in a height and weight range of 157-190cm and 65-75kg respectively. Garments A, B and C were fitted, in a randomised order, to all male participants who met the manufacturer's fitting criteria (the characteristics for each group can be seen in Table 3). Garments A, B and C were selected for use in this study as they were the most frequently used garments for known research studies investigating the efficacy of lower limb compression tights on sport performance and recovery [5,10-11,15-16].

Of the 20 studies, garment A was used in 3 studies, garment B was used in 11 studies and garment C was used in 4 studies.

The ComP was measured using a pressure measuring device (Kikuhime, TT Medi Trade, Søleddet, Denmark) that has previously been validated for use with compression clothing [12]. The device was calibrated at the National Physical Laboratory using a pressure vessel (OerLikon Leybold Vacuum, GmbH, Cologne, Germany) attached to a digital pressure controller (DPI 500, Digital Pressure Controller, Druck Ltd, Leicester). The ComP was measured at 3 sites: the midpoint between the inguinal crease and the superior aspect of the patella of the front thigh; the medial aspect of the calf at the site of maximal girth; and 2 cm above the centre of the medial malleolus of the ankle. The seam on the ankle of the garment was positioned below the distal border of the malleolus. All measurements taken with the pressure measuring device were clear of the seam on the lower edge of the garment and clear of the vertical seam on the garment. ComP measurements were taken with the participant standing in the anatomical zero position with their weight evenly distributed on both feet. Measurements were repeated 3 times with the mean value recorded. Technical error of measurement (TEM) was 0.48 and 0.92 mmHg at the quadriceps and calf, respectively. The pressure measuring device displays values to the nearest 1 mmHg.

Data Analysis

Data collected in part A were analysed using one-way analysis of variance (ANOVA). In the absence of a defined optimal ComP, compression at the quadriceps and calf for a male and female population compared to the minimum recommended ComP of 17.3 and 15.1 mmHg as suggested by Watanuki and Murata, (1994). Data collected in part B were analysed using a one-way ANOVA. A Pearson correlation was also carried out to identify whether any of the measured anthropometric characteristics were related to the ComP at the quadriceps and calf. Where significant differences were observed a *post-hoc* test with a Fisher least significant difference (LSD) adjustment was used to highlight where the differences occurred. Data is presented as a mean value and standard deviations. Significance was set at $p \leq 0.05$.

Results

The anthropometric characteristics of the participants are reported in tables 1 and 3. A one-dimensional ANOVA indicated that there was a significant group difference ($F_{2,77}=92.644$, $p<0.001$) for ComP achieved at the quadriceps. Further *post-hoc* analysis indicated that ComP in the male population was significantly lower ($p<0.001$) than the recommended minimum pressure. ComP at the quadriceps was 9.9±2.9 mmHg, failing to meet the minimum recommended ComP of 15.1 mmHg by 34.4% (Figure 1). ComP achieved in the female population was also significantly lower than the recommended ComP ($p<0.001$). The average ComP of 7.9±1.7 mmHg fell short of the recommended ComP by 47% (Figure 1).

A significant group difference was also observed for ComP achieved at the calf ($F_{2,77}=11.535$, $p<0.001$). Post hoc analysis indicated that there was no significant difference ($P=0.605$) between ideal ComP and ComP at the calf in the male population. Pressure fell short of the recommended level of 17.3 mmHg by 2.9%. There was however, a significant difference between ideal ComP and ComP at the calf in the female population ($p<0.001$). The mean ComP observed at the female calf was 13.9±2.3 mmHg failing to meet the suggested minimum ComP by 19.7% (Figure 1). Individual compression values for the quadriceps and calf can be seen in figure 2.

The second part of the investigation revealed no significant difference in ComP between garment brands at the quadriceps ($p=0.638$) and the calf ($p=0.318$). Compression at the quadriceps fell short of the ideal minimum pressure by 33.2, 28.9 and 30.5% for brands A, B and C respectively; ComP at the calf did not achieve the ideal minimum pressure by 10.5, 13.5 and 4.2% for brands A, B and C respectively (Figure 3). There were no significant correlations ($p>0.05$) between any anthropometric variable measured and ComP at the quadriceps and calf.

Discussion

The primary aims of this investigation were to 1) ascertain the level of ComP exerted by a commercially available CGs when applied to the lower limb in a population of active participants; and 2) to identify whether there was consistency in ComP between different popular brands. Results indicated that there was a large degree of variability in ComP when garments were fitted according to manufacturer's guidelines. In part A, ComP ranged from 4-16.7 mmHg at the quadriceps and from 10.3-25 mmHg at the calf. In part B ComP ranged from 8-15 and 10.3-15 mmHg for garment A, 7.7-16 and 9-22 mmHg for garment B and 6-15 and 10.7-22 mmHg for garment C at the quadriceps and calf respectively.

In addition, ComP fell short of the minimum pressure, suggested by Watanuki and Murata [25], in both the male and female populations at the quadriceps. ComP also fell short of the minimum pressure in the female population at the calf. When three different brands of CG were compared there were no significant differences in ComP at the quadriceps or the calf. It should also be noted that a medium sized CG in three different brands does not fit the same sized population. Garment A was the smallest fitting a height and weight range of 157-190cm and 65-75kg, followed by garment B fitting a height and weight range of 170-190cm and 70-85kg, and C was the largest fitting a height and weight range of 150-185cm and 65-90kg. The difference in populations can be observed in Table 3.

Previous research has caused concerns over whether standardised size categories are effective due to the large variations in anthropometric characteristics within a given population [11]. MacRae et al. [30] indicated that people categorised into one garment size classification, will vary in body shape and size. Indeed this is true of the participants who took part in this study. For example, those fitted with garment brand A exhibited a thigh and calf circumference that ranged from 46.1-56.3 and 33.0-39.5 cm respectively, despite them all meeting the manufacturers recommendations for fitting a medium size garment. It should be acknowledged that some manufacturers now offer bespoke garments, fitted with greater precision by using more surface measurements or using a body scanning device. It is likely that these approaches will improve garment fit and possibly increase the level and consistency of ComP.

The findings of this investigation support concerns identifying that there is wide variation in body morphology and ComP exerted by the CGs tested here. ComP ranged from 4-16.7 mmHg at the quadriceps and 10.3-25 mmHg at the calf in the male population and 5-12.7 mmHg at the quadriceps and 10.3-18.7 mmHg at the calf in the female population. This observation indicates that the suggested minimum pressures of 15.1 mmHg at the quadriceps and 17.3 mmHg at the calf were not being met for the majority of individuals. Individual ComP observed in figure 2 demonstrate the large range in pressure received amongst participants at the quadriceps and calf. Individual data was used for the correlational analysis, the fact that there were no correlation between any anthropometric variable and quadriceps or calf ComP indicates there is a more complex interaction between various anthropometric characteristics and ComP applied by the CGs. This is supported by Troynikov et al [4], who highlighted the need for further investigation into the interaction between the CG and the body of the individual using the garment.

There is no current consensus on how much ComP is required in order to improve indices of performance and recovery. Many of the observed improvements in haemodynamics and subsequent recommendations on the application of compression are derived from clinical studies [28,31]. Brandages et al [31] used CGs that exerted a ComP of 40 mmHg at the ankle decreasing to 21 mmHg at the calf and Ibegbuna et al. [28] used CGs with a reported range of 18-24 mmHg. These ComP appear to have crossed over into the sporting arena with little evidence to suggest the ComP levels are optimum or even effective. It may therefore be possible that the levels of ComP used to treat clinical conditions may not be necessary in an athletic setting [2,32]. Ali et al [2] investigated the effects of three different grades of below the knee, lower limb CGs, low (12-15 mmHg), medium (18-21 mmHg) and high (23-32 mmHg). This study observed that jump height was improved, following a bout of endurance exercise, when participants wore the low and medium grade garments, but not the high grade garment. The authors suggest that muscle function was better maintained in the low and medium grade trials but more research is needed to understand why no improvement was observed in the high grade trial. These findings highlight the importance of understanding factors affecting CG fit, particularly in a performance setting.

Conclusion

A large number of individuals are using CGs to enhance performance or recovery [6], however this investigation demonstrates that the majority of people who use these garments may not be receiving adequate levels of ComP to be of benefit. In addition to this there is a large variation in the range of ComP received from the same brand of garment across a population. This has implications for individuals who wish to use CGs and indicates the need to measure the exact amount of ComP exerted by a CG on each individual.

Knowledge on the ComP individuals receive from these garments is key to interpreting the findings from studies investigating the efficacy of CGs [12], and a greater level of rigour is needed in order to define the ComP achieved in studies of compression garments in sports applications. Given the large range in ComP observed in this study, it is possible that whilst some individuals are receiving insufficient ComP to be of benefit, perhaps others are receiving excessive ComP. This highlights the need to measure ComP pressure in all individuals and may explain why literature investigating the efficacy of CGs is inconsistent, particularly as the majority of the research failed to report the ComP applied to the limb. Future research should 1) measure and control for the pressures exerted by commercially available CGs; 2) investigate whether bespoke fitted garments improve ComP and consequently recovery; 3) identify the effects of different levels of ComP on indices of performance and recovery.

Conflict of Interest
The authors declare they have no conflict of interest.

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Table 1. Anthropometric characteristics of participants. Values are reported as mean±SD.

		Age (yrs)	**Height (cm)**	**Mass (kg)**	**Sum of Skinfold (mm)**	**Waist Circumference (cm)**	**Hip Circumference (cm)**	**Thigh Girth (cm)**	**Calf Girth (cm)**
Part A	Males (n=26)	31.8±8.3	178.3±4.9	78.5±9.3	65.4±23.4	79.3±13.8	98.3±5.3	55.3±4.3	39.1±5.5
	Females (n=24)	29.8±5.2	168.1±8.3	65.4±10.6	101.2±26.6	74.0±7.8	98.2±8.8	53.2±5.0	37.5±3.0
Part B	Males (n=29)	24.5±7.0	177.7±5.1	77.0±6.1	59.8±17.3	81.4±5.6	96.8±6.3	52.8±3.5	38.5±5.1

Table 2. Technical error of measurement (TEM) for anthropometric measures.

Circumference Measures (cm)							
	Waist	**Hip**	**Thigh**	**Calf**	**Ankle**		
TEM (%)	0.4	0.4	0.3	0.4	0.6		
Skinfold Measures (mm)							
	Bicep	**Tricep**	**Sub-scapular**	**Supra-spinale**	**abdominal**	**Thigh**	**Calf**
TEM (%)	2.8	1.6	2.0	1.9	1.9	2.2	2.1

Table 3. Anthropometric characteristics of participants in each of the medium sized garment trials. Values are reported as mean±SD.

	Age (yrs)	Height (cm)	Mass (kg)	Sum of Skinfold (mm)	Waist Circumference (cm)	Hip Circumference (cm)	Thigh Girth (cm)	Calf Girth (cm)
Garment A (n=19)	23.7±5.5	178.1±5.0	80.2±4.3	65.6±17.9	82.4±4.5	99.4±3.8	54.1±3.1	38.3±1.7
Garment B (n=23)	22.5±4.6	177.9±5.3	77.8±3.9	62.7±17.7	82.2±5.5	97.2±6.1	53.0±3.0	37.7±1.7
Garment C (n=22)	24.3±7.1	178.1±5.0	74.4±4.2	58.0±18.4	80.0±5.5	95.0±6.1	51.6±2.8	37.0±1.7

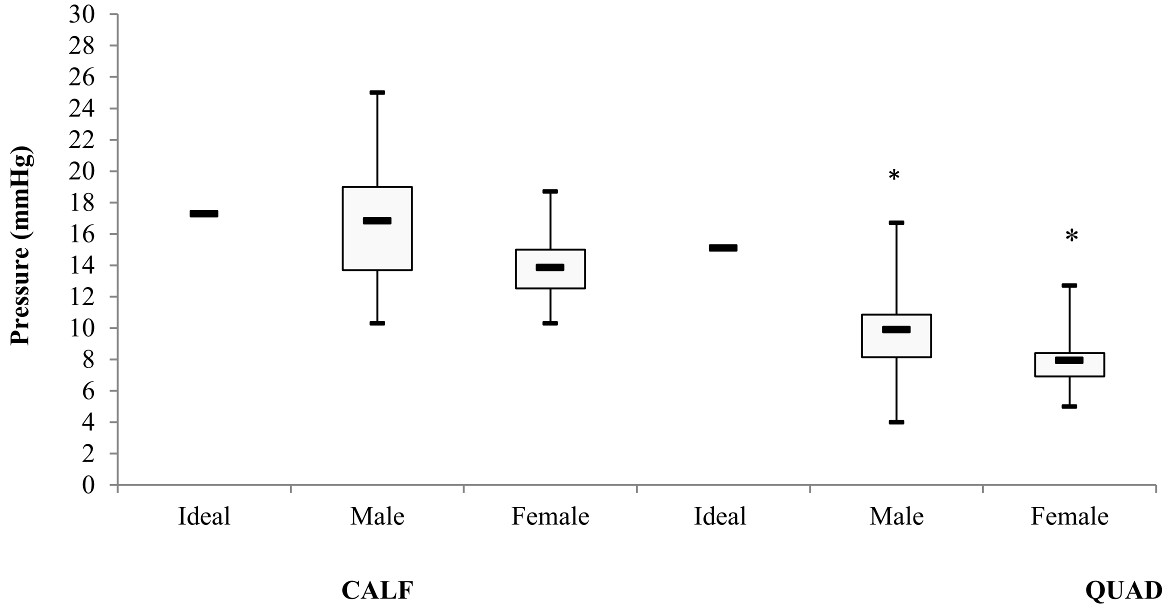

Figure 1. Box plots representing the mean, maximum, minimum and upper and lower quartiles for pressure exerted at the calf and thigh for males and females and compared to the ideal pressure suggested by Watanuki and Murata (1994). * denotes significantly different from ideal pressure ($p<0.05$).

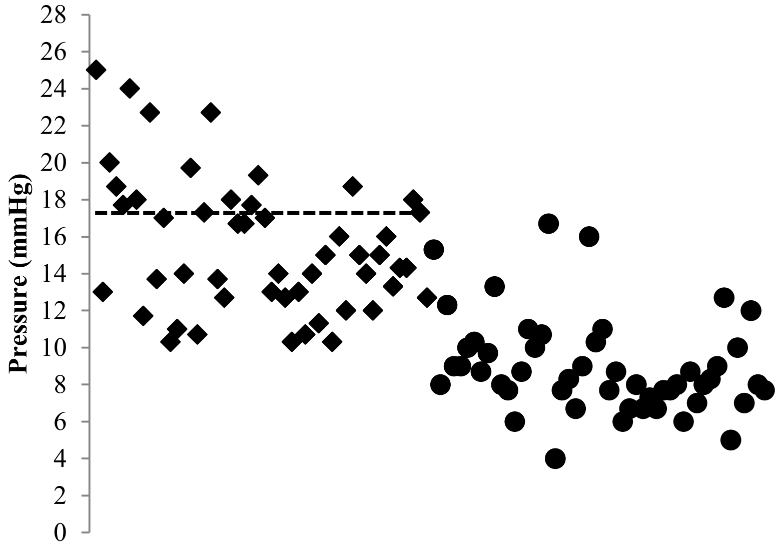

Figure 2. Scatter plot representing the compression pressure received by each individual. Diamonds represent pressure at the calf and circles represent pressure at the quadriceps. Horizontal lines represent the ideal pressure values suggested by Watanuki and Murata (1994) at the calf and quadriceps.

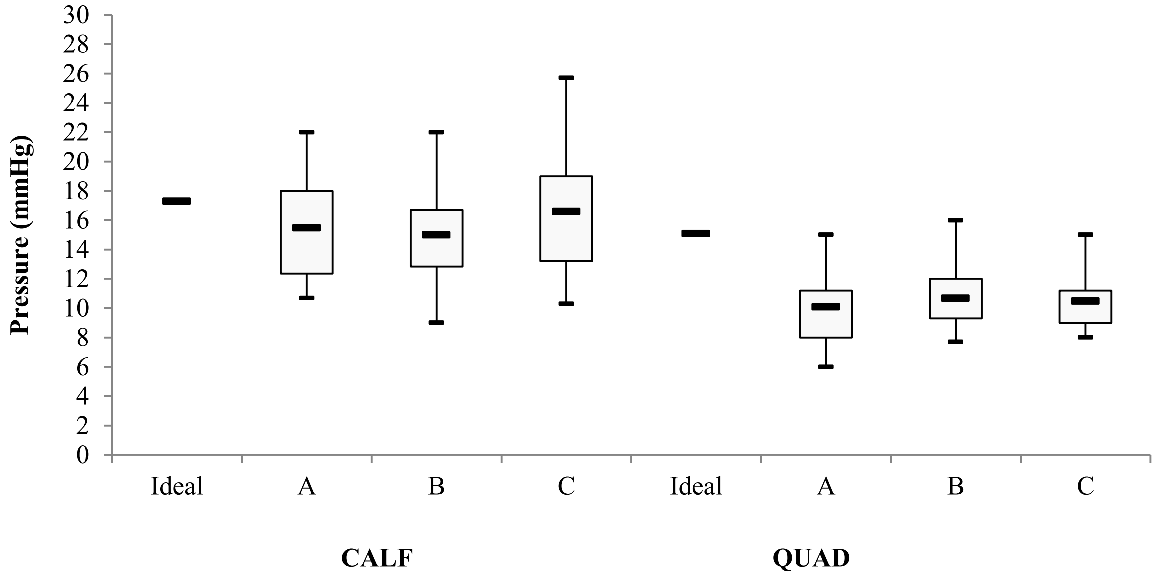

Figure 3. Box plots representing the mean, maximum, minimum and upper and lower quartiles for pressure exerted at the calf and thigh in 3 different brands of compression garment and compared to the ideal pressure suggested by Watanuki and Murata (1994).